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(54) Improvements in electric cables and installations

(57) A single-core electrical power cable for use at 400 kV for example has a relatively high-resistance inner shield 14 located between and insulated from the central core 10 of the cable and its low resistance metallic outer sheath 18. The inner shield is kept continuous throughout the cable run of installations where, for avoidance of currents circulating in the cable sheath, the sheath continuity is broken at spaced-apart locations. By virtue of such continuity, the inner shield provides a continuous path for surges developed in the cable as the result of lightning strikes or switching operations thereby preventing the development of corresponding high transient overvoltages at the outer cable sheath and particularly at the discontinuities therein. It is thus possible to dispense with the surge voltage limiters previously required to be coupled to the outer cable sheath at intermediate positions of cross-bonded systems.

FIG.4.

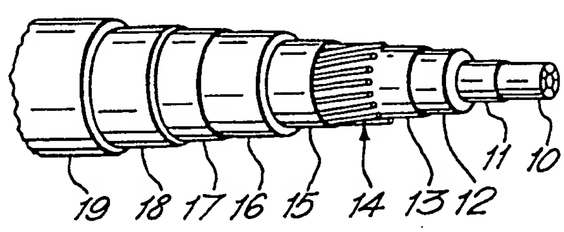

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FIG.1.

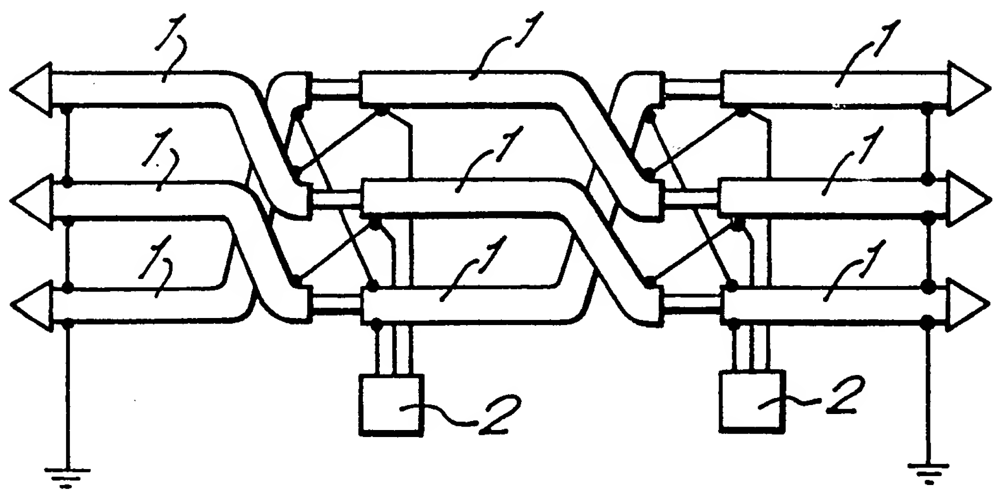


FIG.2.

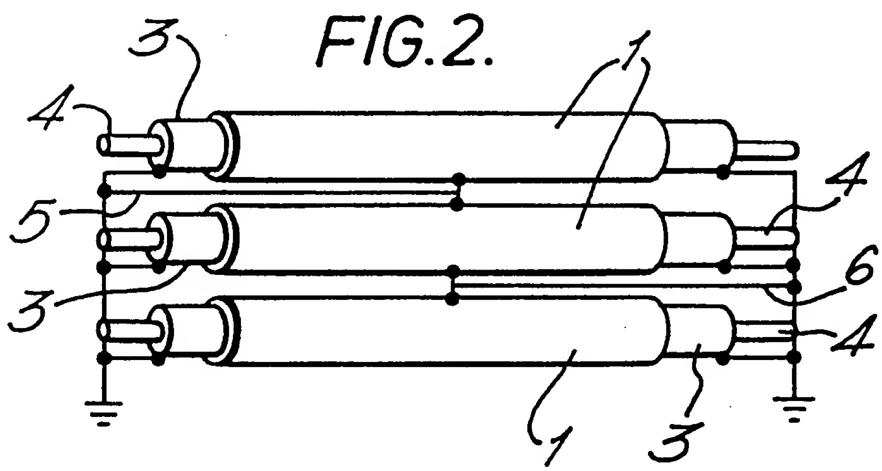


FIG.3.

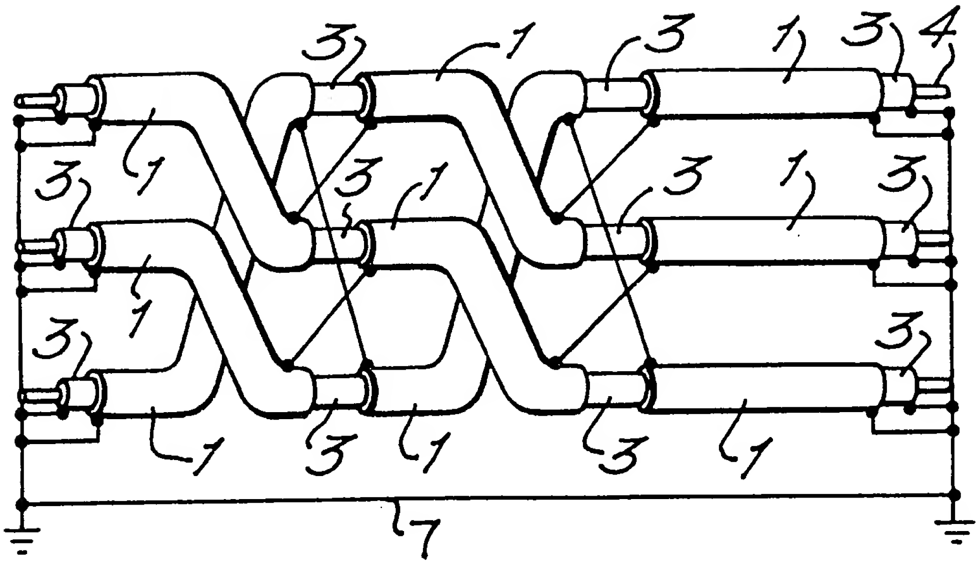
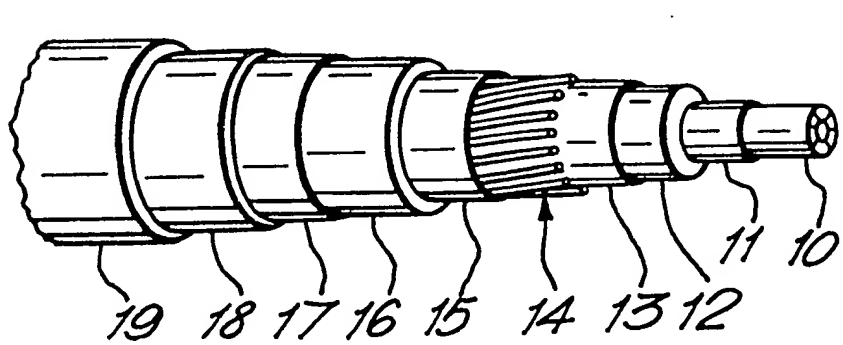


FIG.4.



SPECIFICATION

Improv m nts r lating to electric cabl s and electric cable installations

This invention concerns improvements relating to electric cables and to electric cable installations and is particularly though not exclusively concerned with electric power cables and power cable installations and more particularly with high voltage power cables and installations thereof, for example adapted for use at 132kV or 400kV.

As is well known (see for example the text book "Power Cables—Their Design and Installation" by C. C. Barnes, Second Edition, published by Chapman & Hall Ltd. in 1966) single-core power cables are to be preferred to three-core cables for such high voltages as 132kV and must be used for voltages of the order of 200kV and above owing to the impracticability of manufacturing three-core power cables adapted to such high voltages. The present invention is concerned with single-core power cables and their installation and not with three-core cables.

It has for some time been standard practice in the UK at least when using single-core cables to form a single-phase or three-phase transmission system to bond and earth the metal sheaths of such cables at more than one point, usually at opposite ends of a cable run, for the purpose of short-circuiting the induced sheath voltages which otherwise would appear as the result of transformer action between the cable conductor and its sheath. When the cable sheaths are thus bonded and earthed, the induced voltages are short-circuited but a current flows in the sheath dissipating energy as heat, and in order to eliminate or at least considerably reduce this effect it has also been standard practice to adopt a so-called cross-bonding technique where three-phase groups of single core cables are employed. The cross-bonding technique (see the book by C. C. Barnes abovementioned at pages 238 et seq) provides for breaks in the sheath metallic continuity between adjoining cable sections of equal length, solid bonding and earthing of the cable sheaths at the end of every third cable section, and transpositioning of the intermediate cable sections with cross-connections between the sheaths of the intermediate cable sections to enable the vector sum of the induced voltages to be zero for every three cable sections.

For avoiding heat losses arising from circulating sheath currents in single-core cables it has thus been the practice either to adopt a single-point-bonding or a cross-bonding technique. These methods of special bonding involve the use of sheath sectionalising insulators which enable discrete lengths of sheath, usually single cable lengths, to be cross-connected as necessary so as to cancel the induced sheath emf. Whilst these techiques are quite acceptable and effective when the cable installation is carrying 50Hz three-phase currents and do not introduce significant problems during 50Hz fault currents, they do introduce problems during transients occurring for example due to switching operations or lightning strikes. A transient voltage in the coaxial mode propagating along the cable sheath will, on arrival at a sheath sectionalizing insulator, give rise to a very large sheath voltage which may damage the sheath insulation. To avoid this problem it is normal practice in high voltage cable installations to use sheath voltage limiters at special bonding points. The sheath voltage limiter is usually constituted by a non-linear voltage-dependent resistor or lightning arrester. The inclusion of such sheath voltage limiters in special-bonded single-core power cable installations considerably adds to the cost and complexity of the installation.

The present invention proposes a special form of single-core power cable adapted for special bonding without need for surge voltage limiters. The invention resides in the concept of providing in a single-core power cable an additional inner sheath (hereinafter referred to as a shield for avoidance of confusion with the outer cable sheath) insulated from the cable sheath proper and intended to be maintained continuous throughout the cable run with the cable sheath proper being specially bonded so that the advantages of a specially bonded installation are retained, the resistance of the inner shield being sufficiently high that significant heat losses (such as conventionally arise in single-core cable sheaths which are not specially bonded and which are a function of the resistance of the sheath) are avoided. By forming the inner shield to have a resistance high enough to avoid significant heat losses, and forming the cable sheath proper so as to fulfill its normal functions, namely of providing a path for earth fault currents and a moisture impermeable and hydraulic barrier, cable installations employing special bonding of the cable sheath proper but maintaining the inner shield continuous are not susceptible to the very high surge overvoltages arising with conventional cable installations, this is because in an installation acccording to the invention the travelling wave associated with a switching surge or lightning strike has an uninterrupted path along the inner shield and so suffers no reflection or refraction effects such as give rise to the very high voltages conventionally encountered with conventional installations. The invention thus enables surge voltage limiters to be dispensed with.

According to one aspect of the present invention therefore there is provided a single-core, metal sheathed, power cable incorporating an inner shield continuous throughout the length of the cable and insulated both from the cable core and from the metallic sheath, the inner shield being formed so as to have such a high electrical resistance as abovementioned.

The invention also extends to power cable installations utilizing the power cable according to the inv ntion and particularly to such installations wherein the inner shield of the or each cable or

cables of the installation is continuous throughout the length of the installation (and preferably is earthed at as frequent intervals as possible) and the outer cable sheath of the or each cable is specially bonded for example in the conventional manner hereinbefore described and, in the case where the outer cable sheaths are cross-bonded, preferably with earthing of the cable sheaths at the end of each third cable section and transpositioning of intermediate cable sections.

The power cable according to the invention can for example be of conventional construction other than in respect of the provision of the inner resistive shield. In a typical 400kV oil filled cable design for example, an inner shield resistance of the order of 0.02 ohms/metre would avoid significant heat loss and this might be obtained for example by use of a helically-applied metallic tape or by use of helically-applied fine copper or aluminium wires preferably sandwiched between layers of metallised paper. A layer of insulating paper for example of the order of 1.5 mm to 2.0 mm in thickness might then be applied over this inner shield, followed by a metallised paper and copper woven tape layer for example and the usual lead or aluminium sheath.

As mentioned above, the inner cable shield must be electrically insulated from the outer sheath and such insulation must be capable of withstanding voltages arising in the following operating conditions:—

(i) under 50Hz balanced load, the inner shield at earth potential and the outer sheath at a voltage of up to the order of 100 volts;

(ii) under 50Hz short circuit conditions, the inner shield at earth potential and the outer sheath at a voltage rising typically to of the order of 4kV; and

(iii) under switching or lightning surges, the outer sheath at or near earth potential, and the inner shield rising in potential between earthed points to a level perhaps of the order of 100kV depending upon the shield resistance, the spacing apart of earth points and the magnitude of the incoming surge.

The insulation level must be chosen to suit condition (iii) above but must be such as to be easily punctured in the event of a cable fault so that earth fault current can be transferred to the outer sheath sufficiently rapidly that damage to the inner shield over a substantial length of the cable can be avoided.

Since the outer sheath is screened by the inner shield from the effects of transient voltages, cross-connections between different sheath sections of a cross-bonded system can be made without particular regard to minimising inductance by the use of concentric bonding leads and no sheath voltage limiters are necessary. To economise on overall system requirements as compared with a conventional cross-bonded system it would be practicable in a cross-bonded cable installation according to the present invention to employ link boxes only at every third joint bay of the system, and to make below ground the outer sheath cross connections at intermediate joints. In this way the insulation of the outer sheath to ground could be checked at every third joint bay. The inner shield would be earthed also at the same link box. Such a system would display attractions of economy, especially for long cable runs, by obviating the need for sheath voltage limiters and reducing the number of joint boxes, and has further significant advantages as regards its simplicity and reduced maintenance requirements as compared with conventional installations.

The invention, together with features and advantages thereof, will best become apparent from consideration of the following detailed description in conjunction with the accompanying drawings wherein:—

Figure 1 is a schematic showing of a conventional cross-bonded, three-phase, single-core power cable installation;

Figure 2 shows a single point earthed cable installation according to the invention employing cables constructed in accordance with the invention;

Figure 3 shows a cross-bonded cable installation according to the invention employing cables constructed in accordance with the invention; and

Figure 4 shows schematically the construction of a single-core power cable constructed in accordance with the present invention.

Referring first to Figure 1, shown therein is a typical conventional cross-bonded system in which the cables are laid flat and transposed at each joint between adjoining cable sections. As schematically represented, the outer cable sheaths 1 are solidly bonded and earthed after each third cable section, and at each intermediate cross-bonding position there are surge voltage limiters 2 which, as described hereinbefore, serve to protect the sheath insulation under transient conditions. When the cables are cross-bonded as shown, the resulting sheath discontinuities cause reflection and refraction of the travelling wave set up by a voltage surge, and subsequent reflections and refractions of the initial travelling wave cause large voltages to be seen across the sheath sectionalizing insulators (not shown in Figure 1) and between earth and the cable sheaths, and it is these large voltages which necessitate the use of surge voltage limiters commonly in the form of voltage-dependent non-linear resistors coupling the sheaths to earth.

The invention resides in the realisation that by providing the cable with an inner shield insulated from the main cable sheath proper and continuous throughout the length of the entire cable system, the travelling wave accompanying a lightning strike or switching surge has an uninterrupted path of travel and suffers no reflection or refraction. This eradicates or at least substantially reduces the effects of surge overvoltages and removes the need for surge voltage limiters thereby providing a less expensive and less complicated system requiring less

involvement in its installation and reduced maintenance.

Referring to Figure 2, shown therein is a single-point earthed installation according to the invention. The drawing shows a three-phase installation, but a single phase installation could be similarly configured. As shown, each cable comprises an outer sheath 1, an inner shield 3 insulated from the outer sheath 1, and a central conductor 4 insulated from the inner shield 3. Other components of the cable construction are not shown in Figure 2. As shown the outer cable sheath 1 of each of the three phases is earthed at a single (central) point of the depicted cable run, and the inner shield 3 of each cable is earthed at each end thereof and is continuous therebetween. The arrangement of the single point earthing of the outer sheaths 1 shown in the Figure provides an effective earth continuity conductor 5, 6 for carrying through fault currents. The cable sheaths 1 could alternatively be earthed all at one point (end) of the cable run, and a separate earth continuity conductor provided extending from the earth connection at one end of the inner shield 3 to the earth connection at the other end.

Figure 3 shows a cross-bonded installation according to the invention; the same reference numerals are used in Figure 3 as were used in Figure 2 for the same parts. As shown, the outer cable sheath sections 1 are solidly bonded and earthed at the end of each third cable section with the intermediate cable sections transposed as shown and cross-bonded. The inner cable shields 3 are continuous throughout each cable length and are earthed at each end of the run as shown. An earth continuity conductor 7 may if desired be provided between the two ends of the cable run though this is not strictly necessary.

Figure 4 shows an exemplary form of power cable constructed in accordance with the present invention. As shown, the cable comprises a central conductor 10, which may be ducted for the passage therethrough of oil, a conductive screen 11 enveloping the conductor 10 and formed for example of carbon black paper, a wrapping of paper insulation 12, a further screen of carbon impregnated paper 13, an inner shield 14 according to the present invention comprised of spaced apart fine copper wires helically wound with a relatively long lay so as to provide a resistance as described earlier herein, a further layer of carbon impregnated paper 15 wound over the inner shield 14, a paper insulation layer 16, a metallized paper screen 17, the outer metallic sheath 18 of the cable, and finally as appropriate one or more outer protective layers 19.

The choice of electrical resistance for the inner shield 14 is critical to the concept of the present invention and is a compromise selection between a requirement that it be high enough to cause only a small system derating and it be low enough to carry the normal capacitive current and surge currents without significant voltage drop. Likewise the level of insulation provided between the inner shield and the outer sheath is critical; it must be capable of sustaining normal load conditions, lightning and switching surges and short circuit conditions, but should fail on internal cable faults. A badly designed system subject to an internal fault condition could cause the continuous shield to be irreparably damaged throughout the entire cable length if the insulation did not fail locally to the fault which would considerably increase the cost of repairs to the system following a cable fault.

As an alternative to constructing the inner shield 14 of the cable shown in Figure 4 from fine wires wound helically about the cable, the inner shield could be comprised of lapped metal foil or other conductive tape which might be perforated to facilitate the drying and impregnation stages conventionally employed in the manufacture of such a cable. Furthermore, the insulating layer 16 could alternatively be semiconducting, for example in the form of paper loaded with carbon or with a material such as silicon carbide to provide a non-linear resistivity characteristic; by virtue of such an alternative construction, the cable would tend to exhibit enhanced surge energy absorption with consequent reduction in surge voltages.

Whilst in the foregoing the invention has been described and explained by reference to power cables of the oil filled type, it is to be appreciated that the invention is not limited to installations employing oil filled power cables and could be realized with so-called elastomeric cables wherein the cable insulation consists primarily of elastomeric material. One such elastomeric cable construction might for example comprise a central conductor core onto which there is extruded in a single operation a first layer of semiconducting elastomer constituting a conductor (core) screen, a second layer of cross-linked polyethylene for example constituting the insulation proper and a third layer of semiconducting elastomer, the inner shield of the invention then being constituted by fine wires wound helically on the extruded elastomer of the cable or by corresponding lapped metal foil or other conductive tapes providing the required electrical resistance, a layer of insulation then being provided over the thus-constituted shield, and the outer sheath of the cable being constituted for example by copper wires wrapped helically about the cable and covered with a protective extruded insulation layer. In an alternative construction, the polymeric insulation layer provided over the inner shield could be semiconducting as above described in connection with the oil filled type of cable.

There has thus been described an improved power cable and improved power cable installations in accordance with the present invention which promise a reduction in the cost and complexity of specially bonded power cable installations and in the level of maintenance required.

Claims

1. An electrical power cable installation comprising a single-core cable having a central conductor core, a low resistance outer sheath electrically insulated from the core, and a relatively high-resistance inner shield between and insulated from the central core and the outer sheath, and wherein the inner shield is continuous throughout the length of the cable run of the installation so as to provide a continuous path for surges developed in the cable by lightning strikes or switching operations for example and thereby prevent the appearance on the cable sheath, and particularly at any discontinuities therein, of corresponding high transient overvoltages.

2. An electrical power cable installation as claimed in claim 1 wherein the cable run of the installation comprises a plurality of serially connected cable sections and wherein the cable sheath of each section is electrically insulated from the cable sheaths of the adjoining sections and is connected to earth, and the cable shield of each section is coupled to the cable shields of the adjoining sections and is connected to earth at each end of the respective section.

3. An electrical power cable installation according to claim 2 wherein an earth continuity conductor extends alongside the cable and is earthed to the earthed points of the cable.

4. A three-phase electrical power cable installation comprising three coextensive such installations as claimed in claim 1, one for each phase, and wherein at spaced locations throughout the cable run the outer sheaths of all three cables are longitudinally discontinuous and an earth connection is made to the inner shields of all three cables, each cable section extending between such locations having its outer sheath connected to earth at one or more points.

5. A three-phase electrical power cable installation comprising three coextensive such installations as claimed in claim 1, one for each phase, and wherein the cable run throughout the installation is divided into sections each comprised of three lengths of the three cables, each of said cable lengths having the outer cable sheath longitudinally discontinuous at each end thereof, the cable sheath ends and the cable shields at each end of each said section being coupled to earth, and the cable sheath ends at the two locations intermediate the ends of each section being cross-bonded with transpositioning of the respective cable lengths for each phase at such intermediate locations.

6. A single-core electrical power cable for use in an installation as claimed in any of the preceding claims and comprising a central conductor core, a low resistance outer sheath electrically insulated from the core, and a relatively high resistance inner shield between and electrically insulated from the central core and the outer sheath, said inner shield being adapted and arranged so as in use of the cable to serve as a continuous path throughout the length of the cable for surges developed in the cable by lightning strikes or switching operations for example thereby to prevent the appearance on the cable sheath and particularly at discontinuities therein of corresponding high transient overvoltages.

7. A single-core electrical power cable as claimed in claim 6 wherein said inner shield comprises spaced apart wires wound about the cable with a relatively long lay.

8. A single-core electrical power cable as claimed in claim 7 wherein the said wires are sandwiched between layers of carbon impregnated paper.

9. A single-core electrical power cable as claimed in claim 6 wherein said inner shield comprises a lapped metallic tape.

10. A single-core electrical power cable as claimed in any of claims 6 to 9 wherein a semiconducting layer is provided adjoining the inner shield such that the cable tends to exhibit enhanced surge energy absorption with consequent reduction in surge voltage.

11. A single-core electrical power cable as claimed in claim 10 wherein said semiconducting layer includes a material having a non-linear resistivity characteristic.

12. A single-core electrical power cable as claimed in any of claims 6 to 11 wherein the resistance of the inner shield is of the order of 0.02 ohm/metre.

13. An electrical power cable installation substantially as herein described with reference to Fig. 2 or Fig. 3 of the accompanying drawings.

14. An electrical power cable substantially as herein described with reference to Fig. 4 of the accompanying drawings.

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